Critical Review on Fog Computing

through the paper, "Fog Computing: Survey of Trends, Architectures, Requirements, and Research Directions"

Arthur Lin
Department of Electrical Engineering
National Taiwan University
Taipei, Taiwan
arthurlin0120@gmail.com

***Abstract*—*With the flourish development of Internet of Things (IoT) and Cloud Computing, more and more researches have been conducted to tackle with the requirements in the Internet of Things. These include latency-aware computation for real-time application processing, where the individual utilization of Cloud Computing is of significant limitations to accomplish such performance and might fall short of the required Quality of Services (QoS). One of the derivation, aiming at bridging such technical bridge, is Fog Computing. The idea is a decentralized computing concept. Vaquero et al. [2] claimed that, "Fog computing is a scenario where a huge number of heterogeneous (wireless and sometimes autonomous) ubiquitous and decentralized devices communicate and potentially cooperate among them and with the network to perform storage and processing tasks without the intervention of third parties. These tasks can be for supporting basic network functions or new services and applications that run in a sandboxed environment. Users leasing part of their devices to host these services get incentives for doing so." Though there are various definitions for Fog Computing, it's of importance to differentiate Fog computing from Edge Computing where the former focuses more on the infrastructure side while the latter focuses on the things' side more, according to Shi et al. [3]. To review on the study of Fog Computing, I first goes through the concept of Fog Computing with the support of the discussion conveyed in Naha et al. [1]. Next, I present the advantages and disadvantages of the Fog Computing in presence and their possible outcomes and solutions. Lastly, I make a prediction on the future computing paradigm for IoT with thorough discussion.*

Keywords*—*Fog Computing, Internet of Things (IoT), Fog Devices, Cloud Computing, Edge Computing, IoT Application, Fault Tolerance

I. INTRODUCTION

As we are increasingly relied on the convenience brought about by the smart devices, such as computers and smart watches. The demand for latency-aware computation and/or accuracy with high quality of service are undoubtedly stimulated. According to Naha et al. [1], the number of published research papers with the title cloud computing in the Web of Science climaxed at 2015, but was significantly dropped to half at 2017. The author indicated that the influence of cloud computing would be still important based on the the number of papers; however, as far as the trend concerned, people had started to reach out for alternatives or complements to meet the arising needs. On the other hands, the paper displayed the uprising occurrence of the number of Fog computing-related papers in the Web of Science up to Feb 2018. Though it seemed that fog computing will start progressing from their point of view, it's crucial to verify whether the trends maintain? As mentioned in [4] (see Figure 1 and 2), Figure 1 shows the data obtained from Google Trends for the search term Fog Computing, while Figure 2 shows the total number of publications per year that are indexed in Google Scholar and Web of Science and that contain the term Fog Computing in their titles or keywords. We can conclude that the promising forecasting by previous paper, such as Naha et al. [1], is faced with a plateau in number of papers and the search terms as well in recent

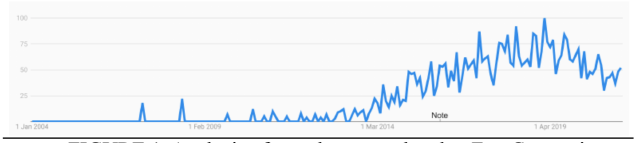

FIGURE 1. Analysis of search terms related to Fog Computing

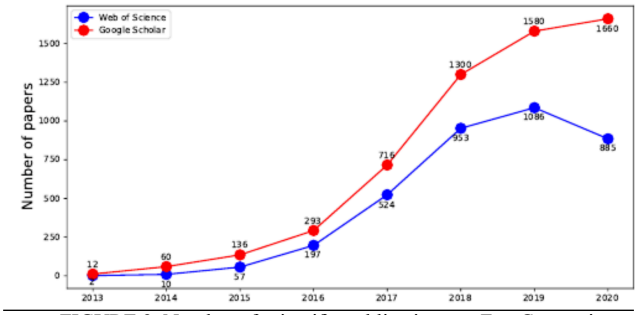

FIGURE 2. Number of scientific publications on Fog Computing

years. We should analyze more detailed on the research realm and possible drawbacks of such concept to better understand the overall prospect of Fog Computing its application, as a result.

II. OVERVIEW OF FOG COMPUTING

A. Definition of Fog Computing

As broadly discussed by Naha et al. [1], the definition of Fog Computing can be first categorized as a computation paradigm that resides in between Cloud and Edge or IoT devices by Bonomi et al. [5]. It can also be considered as an extension of Cloud by Cisco Systems [6]. Though both of Fog and Cloud Computing are independent of centralized cloud and are situated at network ends, Fog is a relatively larger computation paradigm in the aspect of applied range of a single request from users. Through Fog computing, one can deal with latency-aware tasks in a desired time, which can also be properly cooperating with cloud computing to manage non-latency-aware processing and storage to accomplish a hierarchical structure with former computing paradigm.

Besides the vertical combination, one of the critical features of Fog Computing is the horizontal heterogeneous organization. Devices with processing power and storage capacity can act as Fog devices. With the accumulation and cooperation of these Fog devices together, it's possible for Fog Computing to put into practice. Nowadays, many devices like mobile phones, switches, routers, and other network management devices can be utilized as Fog devices. The widespread of available Fog devices in different considered domains enhance the prospect of the development of Fog Computing.

B. Difference Between Fog and Cloud

To better understand the Fog, it's crucial to differentiate the concept of Fog Computing from that of Cloud

Computing. First of all, Fog Computing is based on Fog clusters where heterogeneous combination of Fog devices are used, while Cloud Computing is generally relied on datacenters as main physical components. This will, thus, leads to lower consumption of energy for Fog computing compared to Cloud computing.

In addition, since Fog computing takes advantages of nearby Fog devices, the distance between users and Fog is a lot shorter compared with the distance to Cloud. According to Mahmud et al. [7], it's as short as one or two hops only. The case for Cloud is a multi-hop distance, resulting in a high communication latency.

Last but least, since Cloud computing is a centralized computing paradigm with generally wired connections, it possess the features such as lower rate of failure and easier to manage compared with Fog computing. To manage heterogeneous devices with latency-aware consideration, Fog computing still has a long way to go.

III. Advantages and Disadvantages

In this part of discussion, I will further introduce possible advantages and disadvantages of Fog computing, with critical review on the paper, "Fog Computing: Survey of Trends, Architectures, Requirements, and Research Directions".

A. *Advantages of Fog Computing*

- Power consumption is much lower with the assistance of multiple Fog devices where each devices has low computation capacity, storage capacity and network latency.
- Computation and cooling cost is lower compared with other methods. (Some reviews are made in the C section of the paragraph.)
- Node mobility is high and space requirement is very little.
- The real-time application is achievable using Fog Computing.
- Be able to utilize lots of devices, even any devices, with computation power together to build up several clusters that can finally dynamically reach out and be accessed by everyone at anywhere.
- Some branch of research in Fog Computing, such as Fog-dew computing, facilitates offline services that can work properly without the connection to the Internet.

B. *Disadvantages of Fog Computing*

- Prone to failure with highly diverse because of its decentralized characteristics.
- It mostly utilized wireless connections, leading to lower speed compared with those with only wires or the combination of wire and wireless (e.g. Cloud Computing).
- Since nodes are powered by battery, green energy, or direct power, the functionality of each nodes is difficult to be under control. This may result in higher rate of failure.
- It is more vulnerable towards privacy issues since individual edge devices might be attacked with no sufficient protection. To tackle the problem, even better design is needed to meet the overall functionality with reliability measurements. As a result, additional cost and endeavor are needed to fix the problems.
- The big data issues still exist since billions of devices engaged in the Fog Computing paradigm. More and more researches have worked on to deal with the problems.

C. *Critical Review*

As mentioned in the paper that the computation and cooling cost of Fog Computation is low; however, it's probably not the case considering the overall consumption. To give a high-level idea of the insight, we can first agree on that Fog Computing requires a large number of devices together to function properly. As a result, each devices or sensors should be equipped with additional processing units to enable the heterogeneous integration of different Fog devices. The hardware cost on the whole is also a burden that may be neglected. Recently, some papers have been conducted to utilize artificial intelligence, Deep Learning based method, or smart objects to improve the cost issue of Fog Computing like G. P. R. Filho et al. [8] and Y. Zhang et al. [9]. The cost of Fog Computing at the time when the paper "Fog Computing: Survey of Trends, Architectures, Requirements, and Research Directions" published is still a problem to be further improved. This is the reason why the followed up papers concerning Fog Computing still manage to fix the cost issue.

Besides, the paper also predicted that Augmented Reality will transform the modern world in the near future. This is, however, not accurately describes the current development of Augmented Reality. The paper was published in 2018, which is a time that Augmented Reality undergoes its rise according to Figure 3 from I. Irwanto et al. [10]. Thus, it's not formal enough to make such prediction based on a possible trends without reasoning to support the biased conclusion.

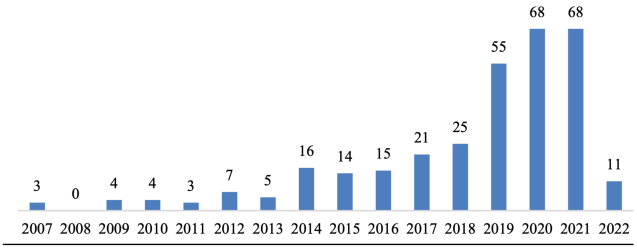

FIGURE 3. Number of publications in Augmented Reality

Lastly, I want to point out another similar issue with over-confident statements. The paper indicates that it's estimated to with 50 billion handheld devices by 2020. In broad sense, handheld devices can be seen equally as mobile devices. According to F. Laricchia [22], Figure 4 illustrates that the number of mobile devices is just 14.02 billion, which is quite different from the prediction. The forecast is in lack of reasoning or reference and is not accurate at all. Thus, the actual situation and the Fog Computing in real world

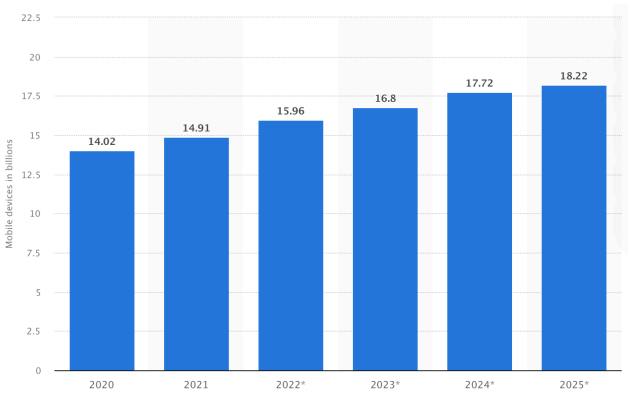

FIGURE 4. Number of mobile devices worldwide 2020-2025

implementation should be reassess in a more careful way. Here, I have tried to give a concise review of my opinion towards the lack of supporting sentences of the paper. The assertions made by the author are sometimes one-sided, which may mislead the reader to the understanding of the development of Fog Computing. In addition, the definition of some terms such as platform, infrastructure, and so forth are not defined at the beginning of the paper. This way of writing may make reader confused about the contents. With the reference to the concept of Infrastructure as a Service (IaaS) and Platform as a Service (PaaS), I believe the reader can understand more about the topic.

However, the paper still give a big picture and detailed descriptions on different research categories in Fog Computing. After reading through the paper, it's capable of knowing what Fog Computing is and why the concept is conceive.

IV. Future Computing Paradigm of IoT

After the aforementioned discussion, supported with papers considering the topic, I will convey my viewpoint toward the future computing paradigm of Internet of Things. I believe the future computing paradigm will be a mixture of Cloud computing, Edge Computing, and Fog Computing. Though not accurate, the percentages of the computing paradigm would be like 2:3:4 for Cloud, Edge, and Fog Computing in my opinion . There are several reasons why I come up with the conclusion.

First of all, not all of our daily computation need a huge computation resource, some tasks demand on speed with little time-latency, however. With the circumstance, it's clear that the ultimate computation paradigm will not hugely depends on cloud for its multiple hops' distance between users and the service center. There are still some difficult tasks that require large computing power to deal with. In this case, Cloud Computing can also play a role in future computing paradigm with slightly fewer percentage. The percentage of Cloud Computing may even decrease with the increase of computing power and storage of each edge devices and/or Fog devices because of the ability of these devices to process more difficult tasks.

Though the paper, "Fog Computing: Surveys of Trends, Architectures, Requirements, and Research Directions" stated that the heterogeneous integration of Fog devices is still impractical for public usage, the concept is feasible once the protocols of different edge devices at user end are set. The integration still needs to be exhaustively researched to alleviate the dependency on Cloud. After such milestone, Fog computing will become a critical role in the combined computing paradigm where data from different sources can be aggregately processed and respond with almost no latency. This not only lessens the expensive cost of Cloud Computing, but also accelerates the overall computing process. The energy consumption or certain frequency bandwidth can be reserved for those required huge computation on Cloud.

Lastly, with the rapid progress of mobile devices, the efficiency and HashRate of single CPU, or even light-weight integrated GPU in the near-future, can allow sophisticated computation that meets our daily needs. It is as well more convenient to accomplish tasks at hand without having a single hop to Fog or even multi-hops to Cloud for computable tasks. The simplicity and independency of further heterogeneous integration with other devices or systems make Edge Computing stands out from the others. Only when the hardware development hits its limitation will the progress of hardware-based computing with no communication between software systems start its saturation. Thus, in my opinion, Edge Computing will ultimately become the most influential character in the future computing paradigm. It can reduce the need for excessive data processing of Fog Computing in the assistance of modern hardware breakthrough on individual device.

V. Conclusion

In this review, I critically examines the concept of Fog Computing as presented in the paper, *"Fog Computing: Survey of Trends, Architectures, Requirements, and Research Directions"*. While the paper successfully introduces Fog Computing as a promising decentralized computing paradigm bridging Cloud and Edge Computing, several aspects need deeper scrutiny. I summarize its advantages, such as reduced latency, energy efficiency, and support for real-time applications, showcase Fog Computing's potential in addressing emerging IoT challenges. However, the there are as well limitations, such as cost, reliability, and scalability, indicates that its practical implementation requires substantial refinement and innovation. The paper's optimistic projections, particularly in areas like Augmented Reality and mobile device adoption, occasionally lack rigorous support and overstate developmental trajectories, leading to gaps between prediction and reality. These discrepancies underline the need for cautious interpretation of trends and a more grounded analysis of Fog Computing's capabilities. Looking forward, the future of IoT computing is likely to be a collaborative framework, blending Cloud, Fog, and Edge paradigms. Each layer plays a complementary role: Cloud for high-capacity processing, Fog for near-user resource aggregation, and Edge for low-latency, localized tasks. Continued advancements in hardware, network protocols, and privacy-preserving designs will determine the extent to which Fog Computing fulfills its potential.

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